Radiant Cooling System Modeling

California Statewide Utility Codes and Standards Program

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California Energy Commission
Staff Pre-Rulemaking Workshop
2013 Title 24 Part 6

May 31, 2011

Background: 2013 Nonresidential ACM Reference Method

- CEC will develop a suite of acceptable modeling results and/or empirical energy performance data
  - For specific nonresidential building types, energy systems and efficiency measures
- This Reference Method will be generated from multiple energy analysis software tools and building heat transfer research studies
- This Reference Method will be used as the basis of comparison during the nonresidential compliance software certification process

Current Code Requirements

- Prescriptive Requirements
  - No specific requirements exist for radiant systems
- Performance approach – Nonresidential ACM
  - For Primary Systems
    - No system type defined for radiant cooling
  - For Perimeter Systems
    - Independent HVAC systems (typically heating only) which serve perimeter zones
    - They do not connect to the primary system but supply heating/cooling through separate air outlets or heat transfer surfaces.
    - **System 12:** Convective/radiant. Zone perimeter system may be a convective or radiant system, such as baseboard or radiant ceiling panels.

Summary of Code Change Proposals

- Performance Approach:
  - Add Optional System Type Description in Nonresidential Alternative Calculation Method (ACM)
  - Proposed design only
    - Does not change the system map for choosing the standard design
  - Floor-based hydronic low-temperature radiant systems
  - Develop defaults/limits for the ACM model

Typical Practice

- For compliance calculations, one can model the radiant system using other system types as proxies
  - Built-up single zone with cooling coil but no fan
  - Four Pipe Fan Coil with adjustments to fan energy
  - Induction Cooling with adjustments to fan energy

Potential for Radiant Cooling

- Radiant Cooling systems being used for high-efficiency designs in commercial buildings
  - PNNL identifies radiant cooling as a strategy to meet 50% better than code performance relative to ASHRAE 90.1-2004
  - Wal-Mart has installed radiant cooling systems in conjunction with dedicated outdoor air systems (DAOS) on several stores
  - Newer products significantly reduce time and labor needed for installing radiant tubes in floors
  - Need for more accurate modeling of radiant cooling system savings when it comes to compliance with Title 24

Data / Findings

- Interviews with Manufacturers/Designers
  - System Types
  - Costs (materials and installation)
  - Energy Savings (calculations and field data)
  - Design Practice regarding sizing and controls
- Review Simulation/Analysis Tools
  - Engineering Analysis Tools
  - EnergyPlus
  - ASHRAE Tool-kit (RP 1383)
- Simulation Inputs
  - Defaults and allowable range of inputs

Summary of Interviews

- 11 Individuals Interviewed:
  - 4 Design Engineers, 5 Manufacturers, 2 Owners' Reps
- System Types Available for Floor-based Installations:
  - PEX pipe systems
  - PEX pipe "mats"
  - Radiant "panels"
- Building Types Suitable for Radiant Cooling:
  - Institutional
    - Airports, museums, universities, churches
  - Commercial
    - "Big-Box" retail
    - Office buildings with lobby or foyer
  - Any building with high solar gains
  - Projects going for LEED

Summary of Interviews

- Design Criteria:
  - Pipe size – ½”- ¾” (5/8” is most common)
  - Pipe Spacing - 6”-9” (up to 12” for heating)
  - Controls for supply water temperature and flow rate
    - Mostly variable temperature with constant flow
    - Some use variable temperature and variable flow for optimized control
    - Some use constant temperature, constant flow as well
  - Thermostatic control of system operation
    - Zone air temperature most commonly used
    - Sometimes based on radiant temperature
  - Time of use
    - Limited use of pre-cooling or night-cooling to charge the mass before occupied hours or outside of peak hours
    - Optimum start or adaptive control used by some

Summary of Interviews: Control Choices

- Four System Operation Choices
  - Constant Volume, Constant Temperature
  - Constant Volume, Variable Temperature
  - Variable Volume, Constant Temperature
  - Variable Volume, Variable Temperature

Summary of Interviews

- Design Criteria:
  - Condensation control
    - Radiant systems control sensible loads only
    - Dedicated outdoor air system to handle latent loads
    - Limit slab surface temperature to dew point temperature plus 1-3 degrees
  - Occupant Comfort
    - Slab surface temperature maintained at or above 66˚F to prevent floors from being too cold

Summary of Interviews

- Analysis Procedures
  - Rules of Thumb
    - Manufacturers will tailor systems to meet loads
      - Load calculations provided by mechanical engineers
    - Manufacturers use finite element analysis or other proprietary tools
  - System Design Tools
    - Energy Plus for system modeling
    - Trane Trace for sizing loads
    - Custom software used by mechanical engineers/designers

Simulation Tools Review

- Engineering Analysis
  - Rules of thumb for heat exchange rate from radiant slab to space
    - 15-16 btu/sqft in best conditions
    - 8-12 btu/sqft heat transfer is typical
    - 4-5 btu/sqft worst case scenario
  - Typical design process
    - Spreadsheet-based tools to size system output
    - Pipe size and spacing (best practices) used to develop water temperature and flow-rate profiles
      - Parametric analysis of pipe sizing and spacing to get desired temperature and flow-rates
      - If system is under-sized, then supplemental cooling is needed with air-side system

Simulation Tools Review

- Compliance with DOE-2.1E
  - Several options to model
    - None explicit in modeling radiant heat exchange
  - Example project
    - Building with floor-based hydronic radiant system
      - Using compliance model for a recently constructed building
    - Option 1 – Modeled as Four Pipe Fan Coil
      - Compliance margin at 12% above code
        - Cooling uses 14% less energy than standard design
    - Option 2 – Modeled as Induction Unit
      - Compliance margin at 16% above code
        - Cooling uses 28% less energy than standard design
    - Engineering calculations predict energy savings beyond code at ~30% for all end-uses

Simulation Tools Review

- EnergyPlus
  - Full-featured energy analysis software has built-in modules for several radiant technologies
    - High-temperature radiant systems
      - – Hydronic or electric
    - Low-temperature radiant systems
      - – Hydronic or electric

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Energy Simulation Tools Review: EnergyPlus

- Low-temperature hydronic radiant systems
  - Define construction where piping is embedded
  - Define pipe diameter, spacing and location
  - Define schedules and controls
    - Variable flow module
    - Constant flow module
  - Control radiant systems based on various control temperatures
    - Space air temp, Mean radiant temp, Operative temp, Outdoor dry bulb temp, Outdoor wet bulb temp

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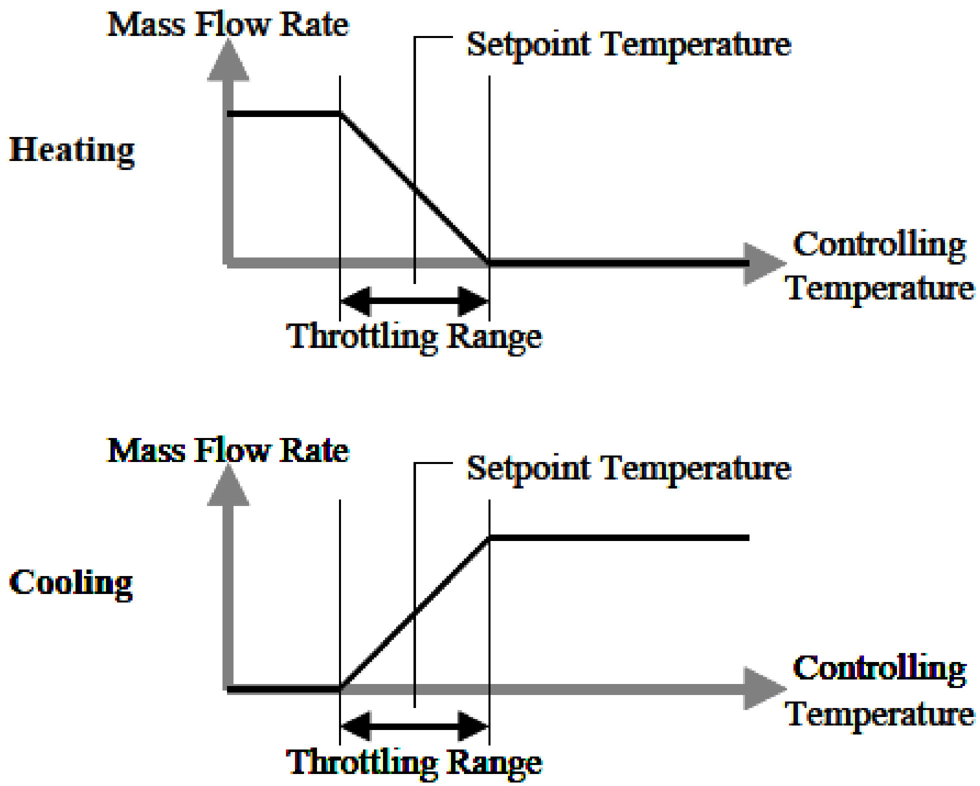
Energy Simulation Tools Review: EnergyPlus

- “Variable Flow” Modeling*



* The variable flow module assumes constant temp

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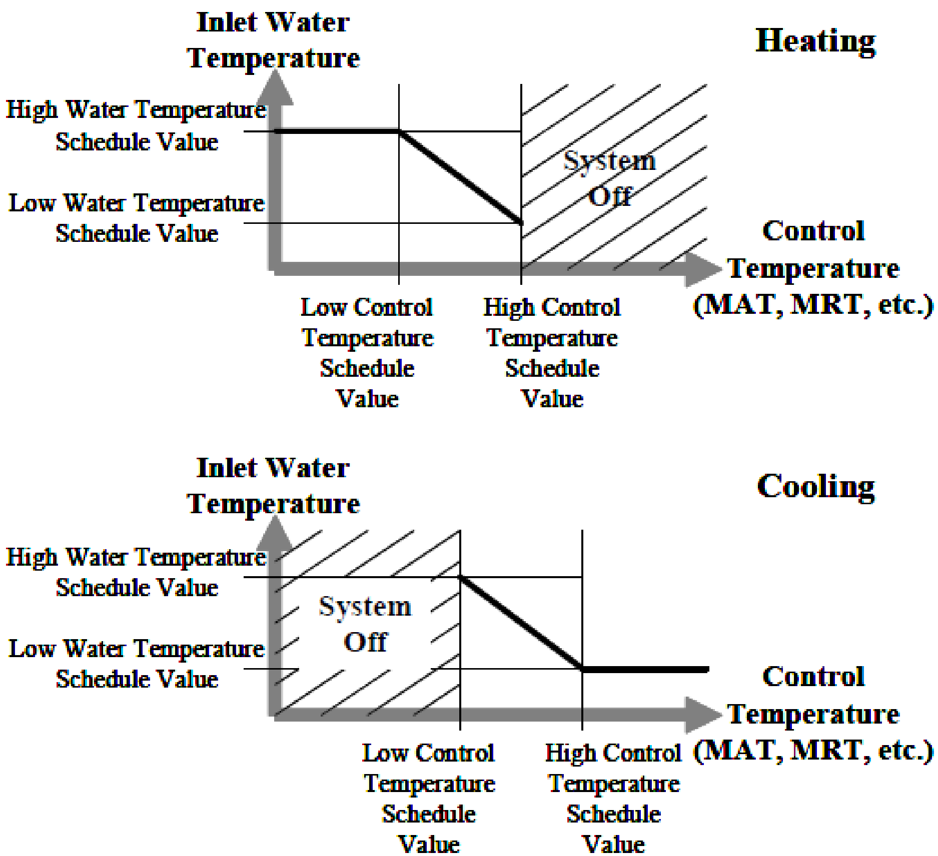
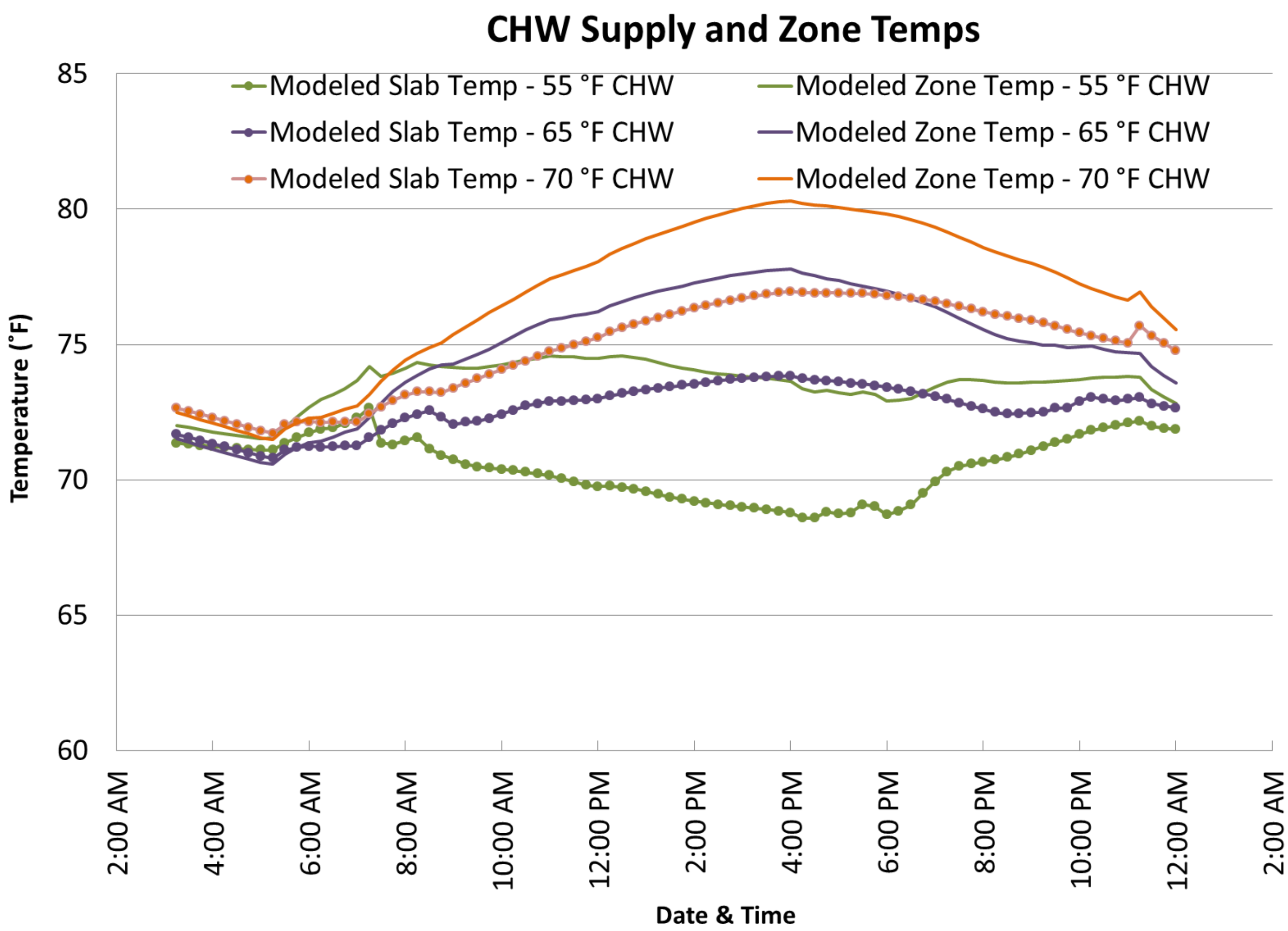
Energy Simulation Tools Review: EnergyPlus

- "Variable Temperature" Modeling



Effect of CHW Supply Temperature



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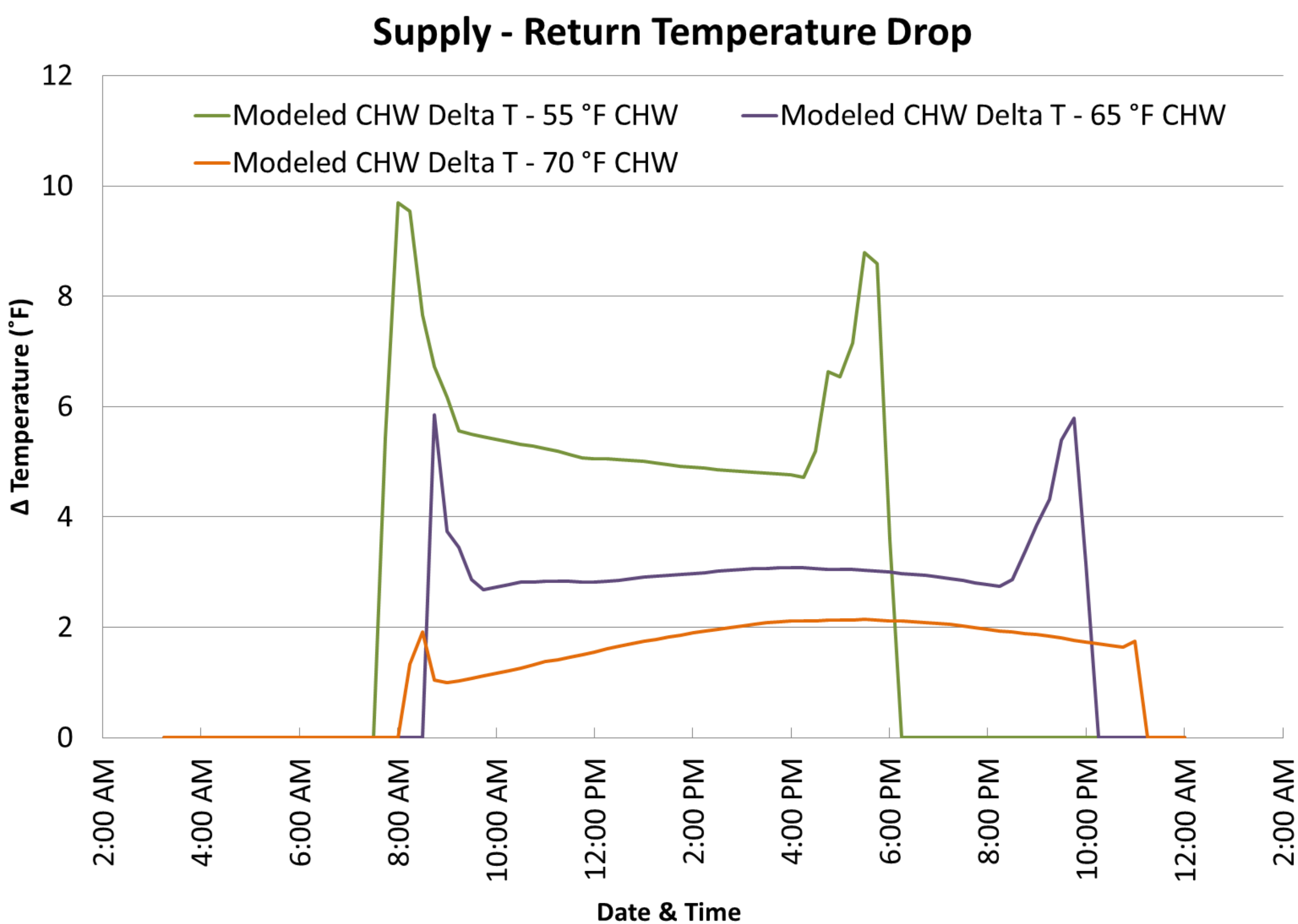

Specifics of Code Change Proposals

- Add Optional System Type Description in Nonresidential ACM
  - Modeling rules for low-temperature hydronic radiant systems
    - Constant flow systems with constant and variable supply temperature
    - Variable flow systems with constant supply temperature
      - EnergyPlus does not explicitly model variable temperature controls with variable flow systems.

Specifics of Code Change Proposals

- Low-Temperature Radiant with Variable Flow

Input Keyword	Acceptable Range by Software	Acceptable Range for Compliance Calculations
Surface Name or Radiant Surface Group Name	Walls, Floors, Ceilings	Floors
Hydronic Tubing Length	X > 0, no max, no default, can auto size	No-autosizing allowed – need specific input. Max 350 ft/loop.
Hydronic Tubing Inside Diameter	X > 0, no max, default = ½”	½”-3/4”
Temperature Control Type	Operative Temperature, Mean Air Temp, Mean Radiant Temp, ODB, OWB	Mean Space Air Temp (use current NACM thermostat setpoints)
Maximum Cold Water Flow Rate	No default, no max	No default, no max

Specifics of Code Change Proposals

- Low-Temperature Radiant with Variable Flow

Input Keyword	Acceptable Range by Software	Acceptable Range for Compliance
Cooling Control Throttling Range	Deg F - No min, no max	User inputs
Cooling Control Temperature	No default	User inputs
Condensation Control Type	Off, SimpleOff, VariableOff	SimpleOff, VariableOff
Condensation Control Dewpoint Offset	No min or max	2 deg F above dew point

Specifics of Code Change Proposals

- Low-Temperature Radiant with Constant Flow

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Hydronic Tubing Length	X > 0, no max, no default, can auto size	No-autosizing allowed – need specific input. Max 350 ft/loop.
Hydronic Tubing Inside Diameter	X > 0, no max, default = ½”	½”-3/4”
Temperature Control Type	Operative Temperature, Mean Air Temp, Mean Radiant Temp, ODB, OWB	Mean Space Air Temp (use current NACM thermostat setpoints)
Rated Flow Rate	No default no max	User input
Rated Pump Power Consumption	No min, no max	User input
Motor Efficiency	0-100%	T24 default for proposed design

Specifics of Code Change Proposals

- Low-Temperature Radiant with Constant Flow

Input Keyword	Acceptable Range by Software	Acceptable Range for Compliance
Fraction of Motor Inefficiencies to Fluid Stream	0.0-1.0 (Default =0)	User Input
Cooling High Water Temperature	Max supply water temp. No limits.	User Input
Cooling Low Water Temperature	Min supply water temp. No limits	Min – 55 deg F
Condensation Control Type	Off, SimpleOff	SimpleOff
Condensation Control Dewpoint Offset	No min or max	2 deg F above dewpoint
Fraction of Motor Inefficiencies to Fluid Stream	0-1.0. Default =0	User Input

Outstanding Issues to Address

- Coordinate development of ACM rules
  - Radiant systems handle sensible loads only
  - Ventilation systems needed for fresh air
  - Need to coordinate with overall ACM development effort for addressing multiple systems
    - And developing a ‘loading order’ for system control

Radiant Cooling

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QUESTIONS & COMMENTS